Disclaimer:

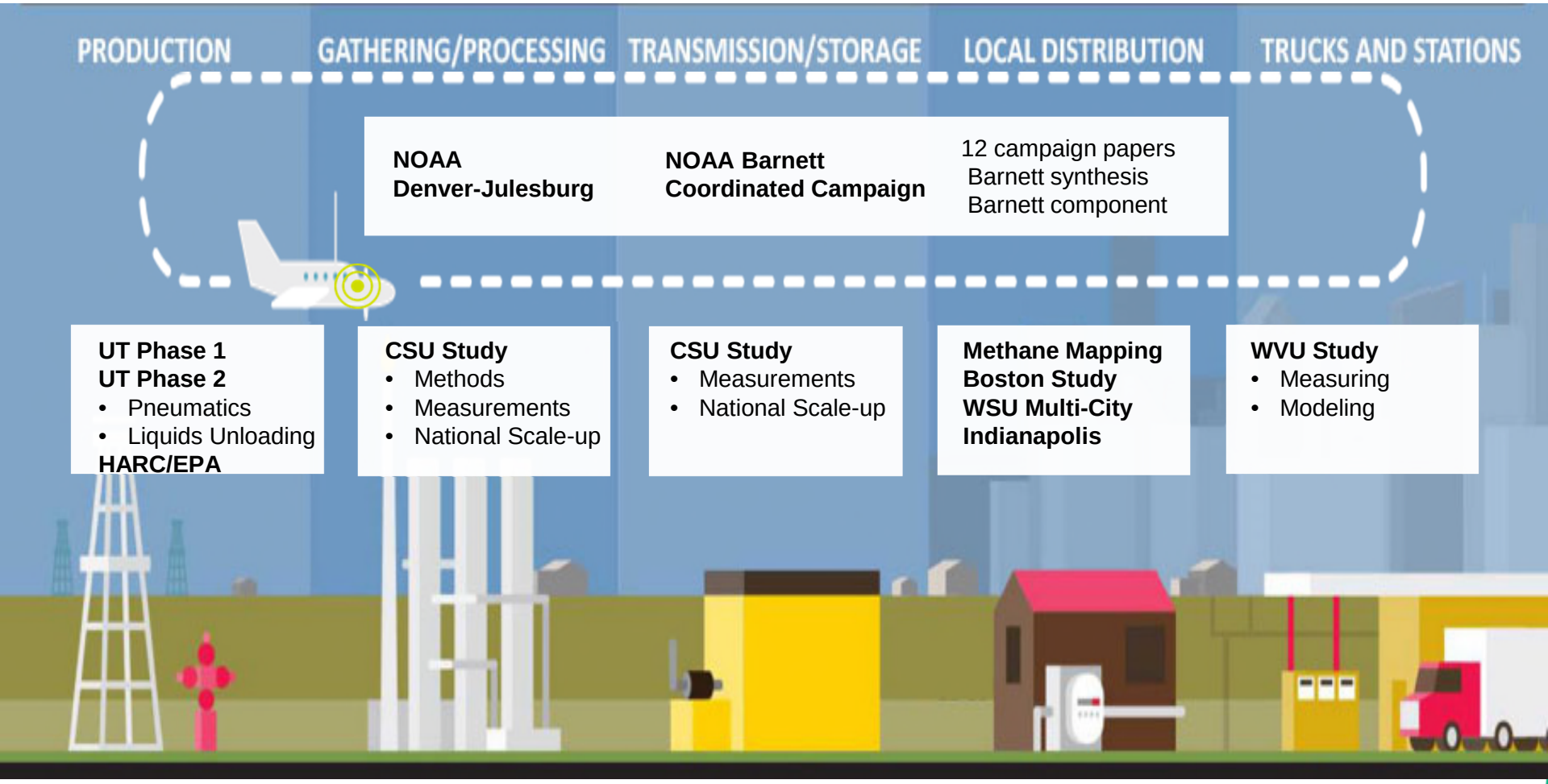
This document was not produced by DEQ. Some of its content may not be in an accessible format pursuant to Section 508 of the federal Rehabilitation Act of 1973, as amended (29 U.S.C. § 794 (d)). Please call 800-592-5482 if you need assistance.

Methane Synthesis Study: Quantifying CH_4 Emissions from the U.S. Oil and Gas Supply Chain

David Lyon
Scientist

EDF
ENVIRONMENTAL DEFENSE FUND®
Finding the ways that work

EDF U.S. Oil and Gas Methane Studies



Pilot Projects

Gap Filling
- Abandoned wells
- Helicopter IR Survey

Synthesis Projects
- NETL LCA
- **Synthesis**

EDF's Methane Research

Science
Studies employ independent experts and use multiple methods to measure methane emissions

Collaboration
More than 130 co-authors from 50 research institutions and 50 O/NG companies

Results
Published in peer-reviewed journals with publically available data

Science

REPORTS

Cite as: R. A. Alvarez *et al.*, *Science* 10.1126/science.aar7204 (2018).

Assessment of methane emissions from the U.S. oil and gas supply chain

Ramón A. Alvarez[1]*, Daniel Zavala-Araiza[1], David R. Lyon[1], David T. Allen[2], Zachary R. Barkley[3], Adam R. Brandt[4], Kenneth J. Davis[3], Scott C. Herndon[5], Daniel J. Jacob[6], Anna Karion[7], Eric A. Kort[8], Brian K. Lamb[9], Thomas Lauvaux[3], Joannes D. Maasakkers[6], Anthony J. Marchese[10], Mark Omara[1], Stephen W. Pacala[11], Jeff Peischl[12,13], Allen L. Robinson[14], Paul B. Shepson[15], Colm Sweeney[13], Amy Townsend-Small[16], Steven C. Wofsy[6], Steven P. Hamburg[1]

[1]Environmental Defense Fund, Austin, TX, USA. [2]University of Texas at Austin, Austin, TX, USA. [3]The Pennsylvania State University, University Park, PA, USA. [4]Stanford University, Stanford, CA, USA. [5]Aerodyne Research Inc., Billerica, MA, USA. [6]Harvard University, Cambridge, MA, USA. [7]National Institute of Standards and Technology, Gaithersburg, MD, USA. [8]University of Michigan, Ann Arbor, MI, USA. [9]Washington State University, Pullman, WA, USA. [10]Colorado State University, Fort Collins, CO, USA. [11]Princeton University, Princeton, NJ, USA. [12]University of Colorado, CIRES, Boulder, CO, USA. [13]NOAA Earth System Research Laboratory, Boulder, CO, USA. [14]Carnegie Mellon University, Pittsburgh, PA, USA. [15]Purdue University, West Lafayette, IN, USA. [16]University of Cincinnati, Cincinnati, OH, USA.

*Corresponding author. E-mail: ralvarez@edf.org

Manuscript and supplementary materials published June 2018 in *Science*
DOI: 10.1126/science.aar7204

Scope of Synthesis Study

- Quantify methane emissions from the U.S. oil and gas supply chain
- Integrates several recently published datasets
  - Production segment emissions based on site-level measurements from 6 U.S. basins
  - Emissions compared to aircraft-based estimates in 9 basins

Drilling & Production

Gathering & Processing

Transmission & Storage

Local Distribution

Regional Research

Synthesis Collaborators

Aerodyne Research
Scott C Herndon

Carnegie Mellon University
Allen L. Robinson

Colorado State University
Anthony J. Marchese

EDF
Ramon A. Alvarez
David R. Lyon
Daniel Zavala–Araiza
Mark Omara
Steven P. Hamburg

Harvard University
Daniel J. Jacob
Joannes D. Maasakkers
Steven C. Wofsy

National Institute of Standards and Technology
Anna Karion

National Oceanic and Atmospheric Administration
Earth System Research Laboratory
Jeff Peischl (University of Colorado)
Colm Sweeney

Pennsylvania State University
Zachary R. Barkley
Kenneth J. Davis
Thomas Lauvaux

Princeton University
Stephen W. Pacala

Purdue University
Paul B. Shepson

Stanford University
Adam R. Brandt

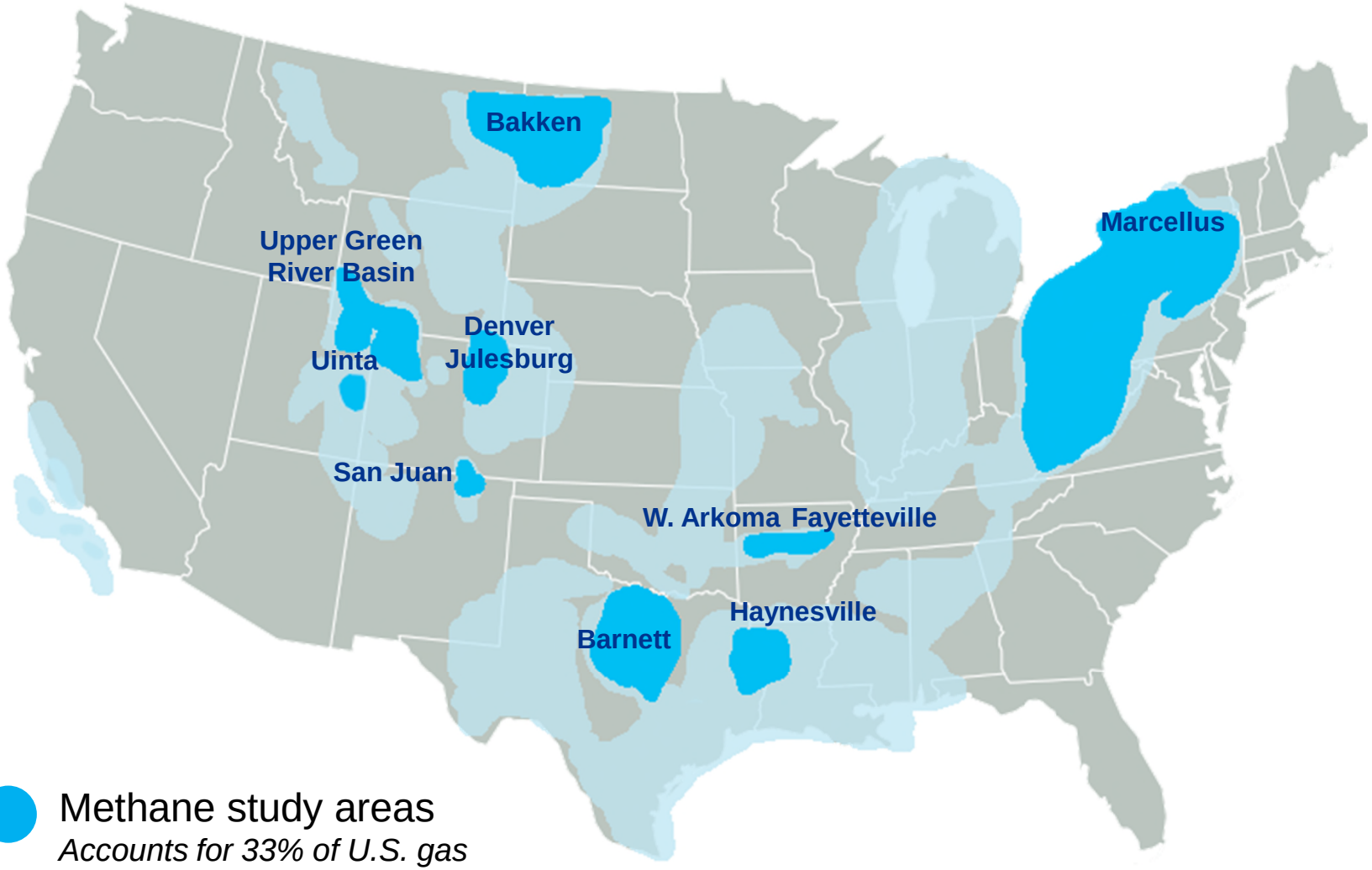
University of Cincinnati
Amy Townsend-Small

University of Michigan
Eric A. Kort

University of Texas
David T. Allen

Washington State University
Brian K. Lamb

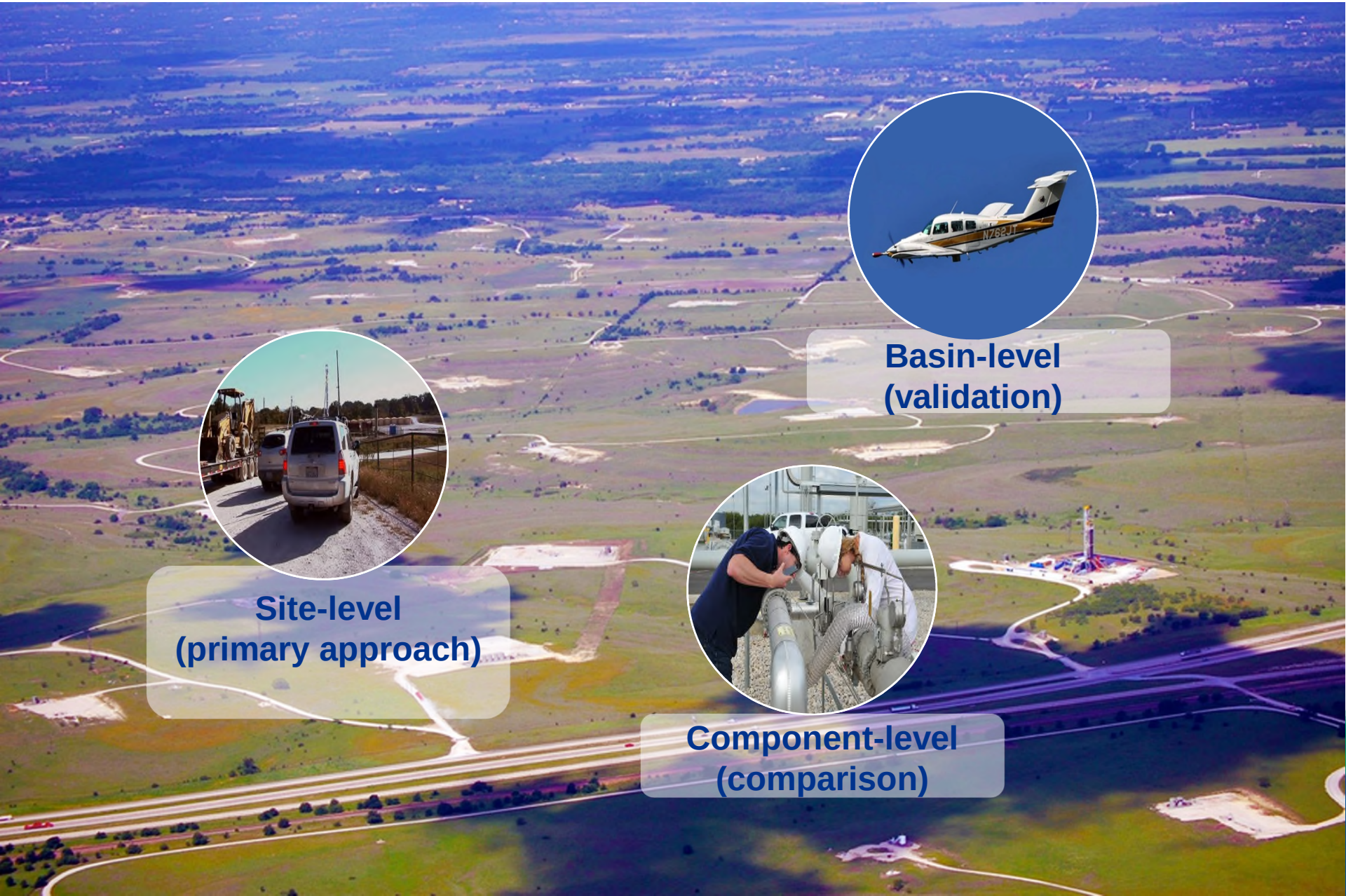
Sources of Regional Synthesis Data



Methane study areas

Accounts for 33% of U.S. gas production; 24% of oil production

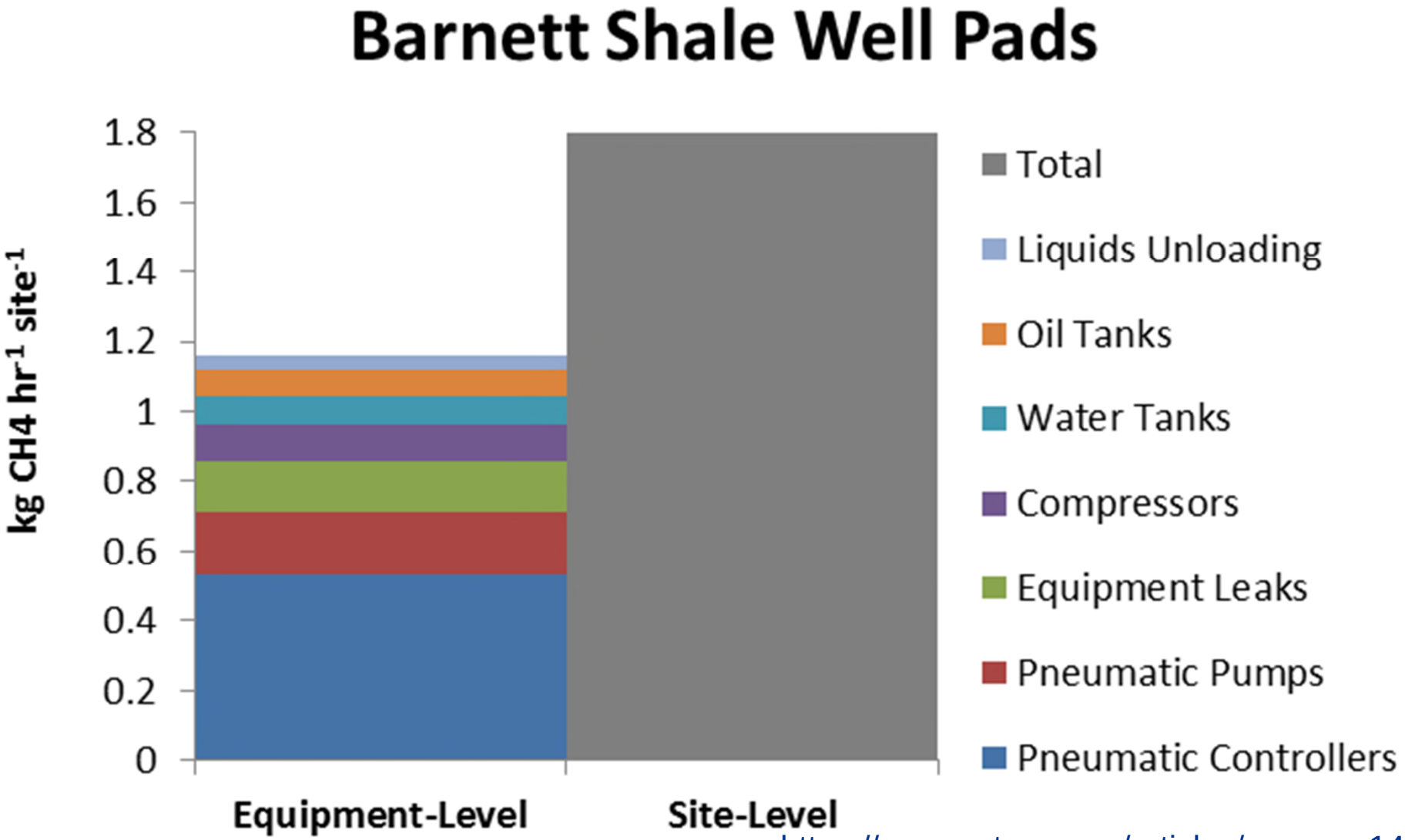
Emissions Quantified at Different Spatial Scales



Comprehensive site measurements reveal higher emissions than inventories

Basin- and site-level quantification methods can find emissions that are overlooked by equipment-level measurements.

For example, site-level measurements find 50% more emissions in the Barnett Shale than estimated by traditional methods

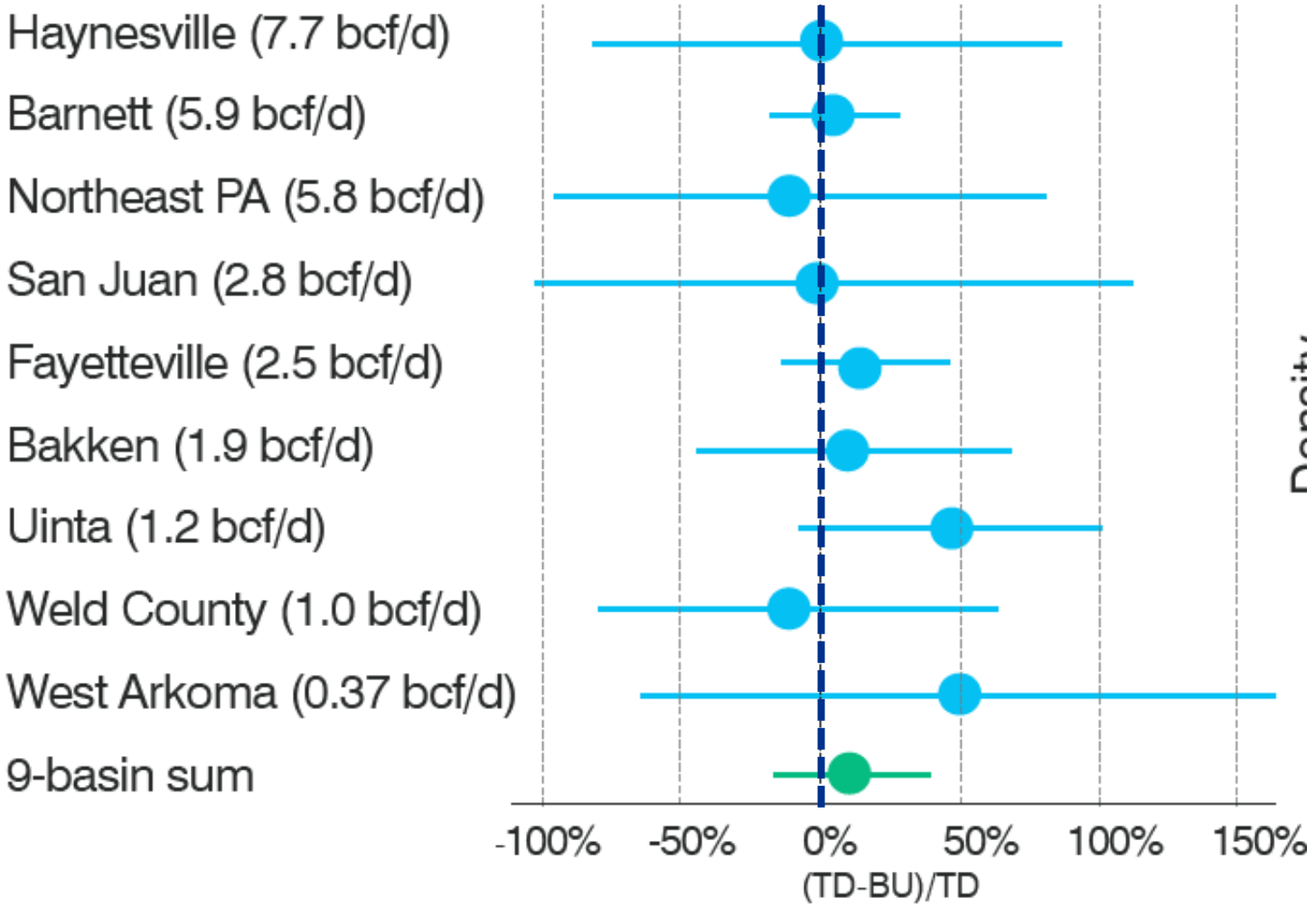


https://www.nature.com/articles/ncomms14012

Synthesis Methods

- Multiple, previously published datasets integrated to estimate 2015 U.S. O&G CH_4 emissions by segment
  - **Production**: >400 site-level measurements from 6 basins
    - Basins: Barnett, DJ, Fayetteville, Uintah, Upper Green River, Marcellus
    - Methods: Dual tracer, mobile flux plane, inverse Gaussian, OTM 33A
  - **Gathering & Processing**: Marchese et al 2015
  - **Transmission & Storage**: Zimmerle et al 2015
  - **Local distribution**: Lamb et al 2015
- Basin-level, site-based estimates validated with aerial mass balance data from 9 basins
    - Basins: Haynesville, Barnett, Marcellus, San Juan, Fayetteville, Bakken, Uintah, Weld, West Arkoma
- Synthesis estimate compared to U.S. EPA GHG Inventory and custom component-based inventory

Aircraft- and site-based emission estimates are statistically similar



U.S. O&G Supply Chain 2015 Methane Emissions

Drilling & Production

7.6 Tg
1.3%

3.5 Tg
0.6%

Gathering & Processing

3.3 Tg
0.6%

2.7 Tg
0.5%

Transmission & Storage

1.8 Tg
0.3%

1.4 Tg
0.2%

Local Distribution

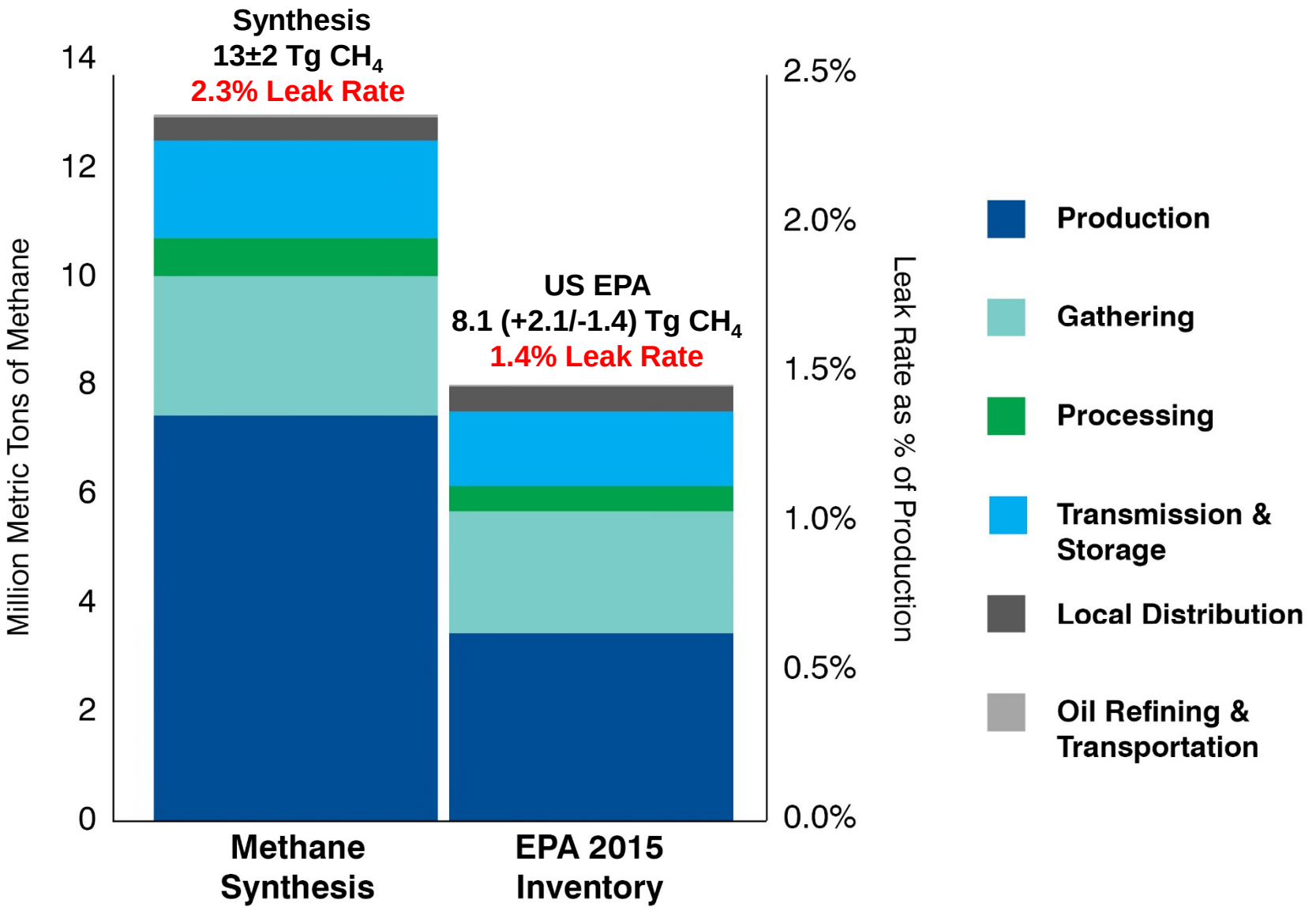
0.44 Tg
0.1%

0.44 Tg
0.1%

Methane Synthesis
Alvarez et al 2018

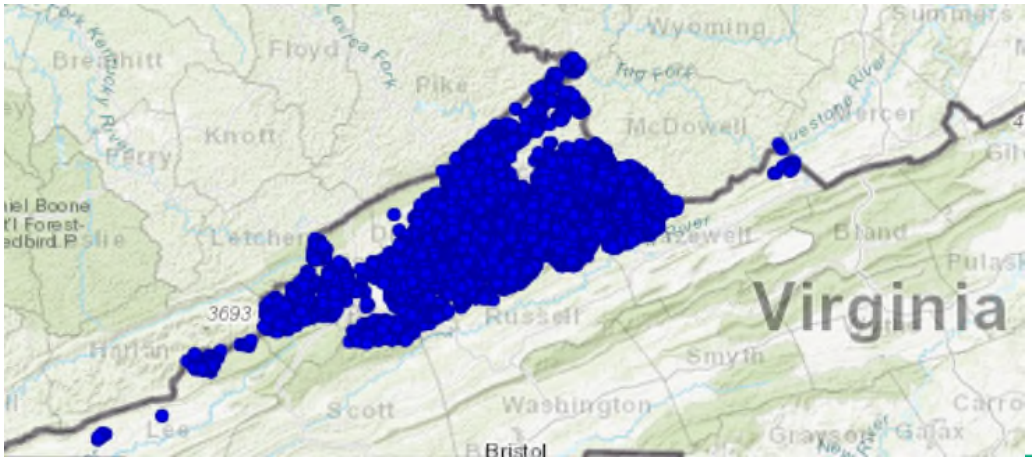
2017 EPA GHG Inventory
(For year 2015)

O&G CH_4 emissions 60% higher than EPA GHGI



Implications for Virginia

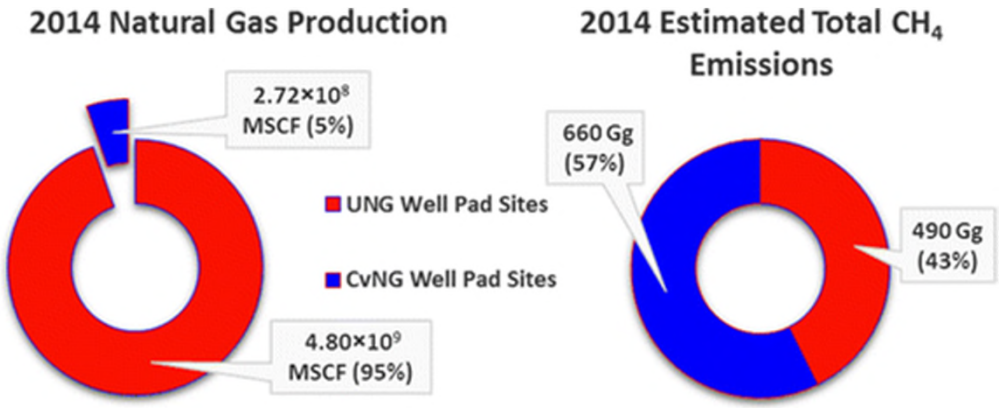
- The state includes approximately:
  - 8,000 active O&G wells
  - 3,000 inactive/plugged wells
  - 25 compressor stations
  - 2 storage fields
- Active wells are almost exclusively marginal gas wells with 94% producing less than 15 barrel of oil equivalents per day.



Drillinginfo

Implications for Virginia

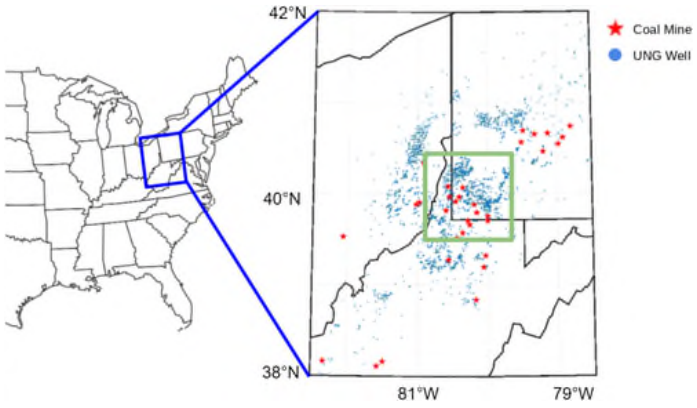
- Measurement data from the state are not available, but studies from a similar production area in southwest Pennsylvania provide insights.
- Marginal conventional wells have relatively low absolute emission rates but very high loss rates:
  - Mean emission factor = 0.8 kg CH_4/hr (7.8 tons per year)
  - Median loss rate = 11% gas production



https://pubs.acs.org/doi/abs/10.1021/acs.est.5b05503

Implications for Virginia

- Another study in SW PA used aircraft data to estimate emissions from O&G and coal mines.
  - Both coal and O&G were important methane sources.
  - EPA estimates were accurate for coal but 5X too low for O&G.
  - Production and gathering loss rate of 0.5±0.3% is in agreement with other regional studies.



https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GL082131

Preliminary Emission Estimates for Virginia wells and compressor stations

- 8,000 active wells * 7.8 TPY = 62,400 TPY CH_4
  - https://pubs.acs.org/doi/abs/10.1021/acs.est.5b05503
- 3,000 abandoned wells * 0.14 TPY = 400 TPY
  - https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2015GL067623
- 25 compressor stations * 739 TPY = 18,500 TPY
  - https://pubs.acs.org/doi/abs/10.1021/acs.est.5b01669

Summary

- **O&G CH_4 emissions are higher than estimated by official inventories like the EPA GHGI**
  - Upstream sources responsible for ~80% of total emissions
  - Site-based estimates validated with basin-level data
- **Abnormal conditions cause large emissions often excluded from traditional inventories**
  - Avoidable issues such as malfunctions, human error, and poor site design can lead to very high emission rates
  - Abnormal conditions account for about 50% of production segment and 33% of total supply chain emissions
- **Regulatory and voluntary actions can reduce emissions**
  - Effective monitoring to quickly detect high emissions
  - Root cause analysis and better site design to minimize the recurrence of abnormal conditions
  - Improved reporting to more accurately understand emissions

Additional Slides

Alternative, source-based estimate is substantially lower than site-based estimate. This traditional approach underestimates emissions by failing to account for uncategorized abnormal emissions.

Industry Segment	Source Category	2015 U.S. Emissions (Gg CH_4 y^{-1})		
		GHGI	This work (source–based)	This work (site–based)
O/NG Production	Pneumatic Controllers	1,800	1,100 (1,100 - 1,200)	7,200 (5,600 - 9,100)
	Equipment Leaks* $	360	620 (570 - 670)	
	Liquids Unloading	210	170 (170 - 200)	
	Pneumatic Pumps*	210	190 (180 - 200)	
	Oil & Condensate Tanks	100	100 (97 - 120)	
	Produced Water Tanks	40	360 (340 - 380)	
	Fuel combustion	240	98 (91 - 210)	
	Associated gas flaring and venting	150	71 (69 - 86)	
	Other production sources*	40	60 (58 - 68)	
	Routine Operations Subtotal	3,100	2,800 (2,700 - 2,900)	7,200 (5,600 - 9,100)
	Completions + Workovers	100	86 (80 - 120)	
	Abandoned and Orphaned Wells	NA	61 (59 - 360)	
	Onshore Production Subtotal	3,200	2,900 (2,900 - 3,300)	7,300 (5,700 - 9,300)
	Offshore Platforms	300	300 (240 - 380)	
	Production Total	3,500	3,200 (3,100 - 3,600)	7,600 (6,000 - 9,600)
Natural Gas Gathering	Gathering Stations	2,000	2,100 (2,100 - 2,200)	
	Gathering Episodic Events	200	170 (7 - 750)	
	Gathering Pipelines	160	310 (300 - 330)	
	Gathering Total	2,300	2,600 (2,400 - 3,200)	
Natural Gas Processing	Processing Plants	410	680 (610 - 880)	
	Routine Maintenance	36	36 (29 - 46)	
	Processing Total	450	720 (650 - 920)	
Transmission and Storage (T/S)	T/S Stations	1,100	1,100 (860 - 1,400)	
	T/S Uncategorized/Superemitters	NA	440 (350 - 570)	
	Transmission Pipelines	220	220 (180 - 290)	
	LNG Storage and Import Terminals	70	67 (54 - 87)	
	T/S Total	1,300	1,800 (1,600 - 2,100)	
Local Distribution	All sources through customer meters	440	440 (220 - 950)	
Petroleum Midstream	Oil Transportation + Refining	34	34 (26 - 84)	
Total U.S. Oil and Gas Supply Chain		8,100 (6,800 – 10,000)	8,800 (8,400 - 9,700)	13,000 (12,000 - 15,000)

Over 30% of emissions are from very marginal (<10 Mcf/d) sites responsible for <1% of U.S. gas production.

Table S4. Distribution of the activity data of U.S. oil and natural gas wells in 2015. The last row shows the percent of emissions from production sites calculated with the model described in this section. The production cohorts in this table were selected based on breakpoints evident in the dataset of production site emission measurements (Fig. S2 and Section S1.9), and 0.68 Mcf/d is the minimum production of the sampled population. The measurement dataset predominantly contains sites with gas production within the bolded gas production cohorts.

	% of US 2015 Activity Data by Gas Production Cohort				
Natural Gas Production Cohorts (Mcf d^{-1})	0	>0–0.68	**0.68–10**	**10–5,000**	>5,000
Sites*	15% (0%)	7.6% (8.9%)	29% (34%)	48% (57%)	0.38% (0.45%)
Wells	19%	5.1%	20%	53%	3.3%
Gas Production	0%	0.015%	0.84%	59%	40%
Oil Production	7.3%	0.49%	3.0%	74%	15%
Emissions*	6.4% (0%)	5.1% (5.5%)	20% (21%)	64% (68%)	4.8% (5.1%)

*The main value includes oil wells with zero reported gas production; the value in parentheses excludes them.